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Original Article

Cognitive and neurological impacts of a biking program in public schools

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Abstract:
Physical activity can enhance physical and mental health across the lifespan and improve cognitive performance. However, the neurological mechanisms influencing cognitive performance through exercise remain obscure. Clarity in the connection between short doses of physical activity and cognitive performance could lend credence to activity programming in the structured academic environment. As such, this manuscript presents the immediate impacts of a brief biking experience during physical education classes on neuro-cognitive processes. A total of 46 middle and high school-aged adolescents completed cognitive tests before and after participation in a single biking event, as part of a nine-week course curriculum. Participants wore encephalographic (EEG) headsets throughout the process, to measure changes in neuronal activity across conditions. Findings indicate that a brief (15-minute) dose of low to moderate physical activity can induce significant changes in cognitive performance and EEG-based indicators of focus, motivation, and relaxation. Effect sizes equal those reported in previous research and in FDA-approved alternative therapies (i.e. neurofeedback). Working memory was elevated after exercise, though partially confounded by time of implementation. These findings suggest that short doses of physical activity during times of mental fatigue can enhance neuro-cognitive processes, supporting academic performance and mental health.
Key words: **Physical activity, EEG, cognitive performance, attention restoration**

Introduction

Physical activity consistently demonstrates a positive influence on various health indicators and cognitive performance, though evidence on adolescent populations remains lacking (Biddle, et al, 2019). Despite evidence of the positive influence of exercise, physical inactivity levels remain alarmingly high, and public school settings often devalue physical education (Haskell et al., 2009; Hills et al., 2015). The World Health Organization (2019) recognizes early intervention and routine implementation as key factors in establishing long-term healthy behaviors. Additionally, instruction in low-impact activities (e.g. biking), that can be enjoyed outside of a formal setting, may enhance health outcomes across the lifespan (Furzer et al., 2021). While the outcomes associated with routine exercise, as well as preventive and prescriptive interventions are promising (Heath et al., 2012), the mechanisms of influence remain dubious (Lubans et al., 2016). A dearth of knowledge connecting neurological mechanisms to cognitive performance represents a significant gap in exercise research (Biddle et al., 2019). As such, this manuscript details two studies utilizing cognitive tests and electroencephalography (EEG) to assess the mental influence of a biking program implemented during standard public school scheduling.

Physical Activity and disease prevention

Health outcomes associated with routine physical activity are well-documented. The likelihood of diabetes, obesity, heart disease, and some forms of cancer can be mitigated through regular exercise (Heath et al., 2012). Sedentary behaviors may also impede mental health and cognitive performance. Symptoms of depression, anxiety, self-esteem, attention deficit disorders, and cognitive impairment have all shown positive improvement with exercise (Biddle & Asare, 2011; Ziereis & Jansen, 2015). Health impacts are most notable when achieving the recommended physical activity dose of 150 minutes per week for adults and 60 minutes a day for adolescents (CDC, 2017). Most of the U.S. population fails to meet this mark, with greater than 30% of adults in the region of study reporting no leisure time physical activity, and only one in five public school students reporting an hour of activity each day (Chattanooga, Hamilton County Health Department; CHCHD, 2011). Moderate to high intensity activities (e.g. biking, running) maximize positive impacts, but even light exercise (e.g. walking) enhances health and well-being (Mandolesi et al., 2018; Ploughman, 2008). Researchers posit that relaxed and meditative mental states induced by physical activity reduce cognitive loads and replenish needed resources to enhance health and performance after exercise (Bailey et al., 2018; Gutmann et al., 2015). Long-term engagement in regular physical activity may even influence the development of cognitive resources and increase cortical volume (Petersen et al., 2020). Engineering routine doses of exercise into the standard school schedule may enhance academic performance, aid the achievement of activity standards, and contribute to long-term healthy habits.

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Cognitive Performance

An individual's ability to focus on a task, prioritize relevant information, and persist to successful completion, is essential for academic success, mental health, and life satisfaction (Biddle et al., 2019; Sternberg, 2003). Cognitive performance improves with acute and routine physical activity, though an understanding of the influence of exercise on neural mechanisms is lacking. Baddeley's (1981) model of working memory presents a popular framework to comprehend changes in cognitive function. In this conceptualization, working memory is controlled by the central executive system (CES), which orients attention to relevant information and coordinates resources to other "slave systems", such as the phonological loop and the visuospatial sketchpad. The phonological loop stores written and verbal information until it can be committed to long-term memory. This system is commonly assessed through the recall a sequence of numbers (e.g. Digit Span Task), or speed and accuracy of color and word identification (e.g. Stroop Task). Such measures have been used to document the positive influence of physical activity and natural environments on cognitive performance in adolescents and adults in past research (Bailey et al., 2018; Biddle et al., 2019; Faber-Taylor & Kuo, 2009), and are included in the first study in this manuscript.

The visuospatial sketchpad facilitates the short-term retention of pictures and patterns, or visual working memory (VWM). VWM is associated with fluid intelligence and aptitude in youth (Cowan et al., 2006), with lower capacities for pattern retention being tied to poor performance and attention disorders (van Ewijk et al., 2014). Psychological assessments for VWM, not being reliant on language or color identification, are feasible for all ages and across language barriers (Isbell et al., 2015). The second study in this report incorporated a common VWM assessment (the Match to Sample task), to investigate the influence of physical activity on function of the visuospatial sketchpad.

The neural mechanisms underlying attention and working memory remain elusive, though recent research provides some clarity. Activation of the frontal and parietal lobes is a good indicator of working memory processing in adolescents and adults (Cavanagh & Frank, 2014; Rosenberg et al., 2020). Functionally, this signifies connectivity between the sensory (i.e. parietal) and executive (i.e. frontal) regions of the cortex, promoting heightened focus and awareness, as well as inhibitory control to direct attention toward relevant information (Coelli et al., 2015; Cavanagh & Frank, 2014). The resources required for focus and inhibitory control may be depleted through constant stimulus processing, such as paying attention in class or interacting with social media (Pattyn et al., 2008). Conversely, physical activity promotes mental relaxation, providing a regenerative effect that may enhance attentional control post workout (Gutmann et al., 2015). An understanding of cortical activity across exercise and working memory conditions would connect neural processes to cognitive function, and prove instructive for efficient activity interventions.

In addition to working memory, creativity can be instrumental for academic and career success. Divergent thinking facilitates the connection of new information with other stored or imagined data to create new models and suppositions (Guilford, 1967). As such, it plays a central role for innovative problem solving. Though tricky to measure, creativity has been associated with compassion, social-emotional intelligence, intrinsic motivation, optimism and mental health (Cropley & Greaves, 2015; Florida, 2005; Sternberg, 2003). Creativity improves during light-intensity physical activity, though the influence may be short-lived (Oppezzo & Schwartz, 2014). Current hypotheses posit that full-body movement generates connectivity across the corpus callosum, a concentration of neurons facilitating communication between the left and right hemispheres of the cortex. However, this heightened connectivity may only exist during physical activity, rendering effects difficult to capture. To determine if moderate exercise may have measureable lasting effects, a divergent thinking task was incorporated into the second study described below.

Biometric Tracking

Much cognitive and activity research has relied heavily on self-report measures and written tests. While these methods provide valuable results, they can be susceptible to various forms of bias, and may perform inconsistently with various populations (Bailey et al., 2017; Gorber & Tremblay, 2016). Our study employed psychometric assessments coupled with portable electroencephalographic (EEG) headsets to assess neuro-physiological changes across conditions. EEG devices have been used for decades in laboratory settings to monitor brain activity via electrical signals collected at specific cortical locations (Thompson et al., 2015). When processed into discrete oscillatory frequencies, these signals can infer moods, mental states, and processing activities. In general, faster oscillations (e.g. Beta frequencies; 15-30 Hz) indicate higher levels of mental activity, such as concentration, stress, and excitement. Delta (< 0.5Hz) and Theta (0.5 – 8Hz) frequencies, by contrast, signify drowsiness, daydreaming, and/or inward attention. Finally, Alpha (9-14Hz) power is associated with a relaxed mind, prepared for action (Thompson et al., 2015).

Portable, affordable EEG devices have facilitated a boon in neuroscience research, aiding with the identification of reliable indicators for mental states. Additionally, new technologies render EEG analyses during activity more feasible, with cycling research becoming common in the literature (Enders et al., 2016; Ludyga et al., 2016). This study incorporated four EEG-based indicators, as established by previous research. Focus was measured as the beta/alpha ratio from two sensors on the frontal lobe (af3 & af4), with higher amplitudes indicating elevated levels of neuronal activity in the executive area of the prefrontal cortex (Coelli et al., 2015).

This measure denotes frontal lobe activity consistent with working memory processing. Motivation (i.e. interest & enjoyment) was measured as alpha asymmetry in the frontal lobe (V = α af3 – α af4), with higher relative alpha activity on the right frontal lobe (af 4) indicating higher valence (Zhao et al., 2018). Feelings of enjoyment during or after exercise may enhance cognitive performance and future participation in physical activity (Furzer et al., 2021). Inward attention was measured as theta band power in the frontal lobe (af3 & af4) combined with alpha power in the parietal lobe (pz). This measure is associated with inhibitory mechanisms and a focus on internal thoughts, which could be indicative of attentional loads or meditative states (Cavanagh & Frank, 2014). Finally, relaxation was measured as global alpha power across five sensors (R = α(af3, af4, t7, t8, pz)). This measure is consistent with previous research demonstrating relaxation post-exercise (Gutmann et al, 2015). Emotiv Insight® headsets were used to collect EEG data, given their ease of setup and reliability in previous research. The quality of signal recordings generated by the Emotiv headsets has been verified as comparable to standard laboratory devices (Badcock et al., 2015) and their low-profile design allowed for placement under a bike helmet. These headsets employ five semi-dry polymer sensors to collect signals at a rate of 128Hz from five cortical locations (af3, af4, t7, t8, & pz). A proprietary filtering process reduces artifacts and transforms the raw data into discrete brainwave bandwidths (theta, alpha, low beta, high beta, and gamma) through Fast Fourier Transformation (FFT). The final FFT data, observable at a rate of twice per second, were transformed into the five mental indices described above through Python coding, and visually scanned to remove obvious noise (< 5% of data removed). If a large portion of data for an individual session were contaminated with artifacts (>20%), the entire dataset was removed from analysis. This occurred only during the second study, as multiple visits complicated efficient participant preparation. Based on the theoretical framework thus described, two studies were implemented addressing two research questions.

RQ1: Can a short biking experience enhance cognitive performance?

RQ2: How does a short biking intervention influence neuronal activity?

Methods

Participants for these studies were recruited from a public middle school implementing the Outride® curriculum promoted by the Specialized Bicycles®. This program encourages physical activity in public schools by providing resources and guidance to local physical education teachers. No support, monetary or otherwise, was obtained from the Specialized Foundation. Students progressed through a mountain-biking curriculum over the course of nine weeks. At the time of data collection, students were approximately five weeks into the program and were all comfortable riding on flat terrain. This point in the curricular progression was chosen to ensure that all students were proficient with basic biking skills. A total of 46 students freely chose to participate in these two studies (with personal and parental consent) and no incentives were provided.

IRB approval was obtained for each study, including consent from the school, students, and parents. Per administrative restrictions, data collection occurred during their normally-scheduled physical education class, which was split roughly into thirds: 15 minutes of setup and pre-test, 15 minutes of biking (or control), and 15 minutes of post-test. Upon arrival, students were fitted with EEG headsets and fitness trackers, and provided with a cellular phone to collect physiological data and cognitive test scores. With the exception of creativity tests, all data were stored on these cellular devices and coded by ID number. Time stamps were recorded by the researchers in order to create time-bound epochs for EEG analysis, including: 1) Baseline, 2) Pretest, 3) Bike or control, and 4) Post-test. Cognitive tests occurred in the school field house and all biking conditions occurred on an outdoor track, adjacent to the school. Study 1 was exploratory in nature, observing neurological changes across tasks, and documenting connections of neural indicators to working memory. Study 2 built upon those initial observations to assess VWM and creativity with the addition of a control condition.

Study 1

Sample and Procedures

In the first study, 24 participants (14 female, *Mean* age = 14) completed a working memory test before and after a short bike ride on an outdoor track. These students represented a diverse sample, with 14 Caucasians, four Hispanic/latinos, and six African-Americans. The Stroop task was utilized via the EncephalApp® iPhone application (Bajaj et al., 2015) to measure psychomotor speed, accuracy of response and cognitive flexibility (i.e. task switching). This is a common working memory test, where participants are presented with words or symbols in various colors, and they must select a button at the bottom of the screen corresponding to the color of the font. In adherence with procedural recommendations, participants were read the instructions aloud, then directed to complete a total of 14 short Stroop events in the following order: 1) Two practice runs with stroop off (i.e. hashtag symbols in the corresponding colored font), 2) five scored runs with the stroop off, 3) two practice runs with the stroop on (e.g. the word "yellow" written in green font), and 4) five scored runs with stroop on. If participants pressed the incorrect response, they started that run over and continued until they completed five runs in each of the on/off positions without a mistake. This process has shown robust test-retest reliability (intraclass coefficient = 0.83) and resistance to learning bias (Bajaj et al., 2015).

After completion of the pre-test, students circled the track on mountain bikes for 15 minutes under the supervision of the class instructor. They were encouraged to remain in motion for the duration of the process, though students could choose their level of intensity. Upon completion of the bike-riding portion, students returned to the field house to complete the same Stroop task as described for the pretest. When all testing was complete, EEG headsets and fitness trackers were removed and the students dispersed to attend subsequent classes.

Results

Stroop test results were analyzed in SPSS using a paired samples *t*-test. Total time required to complete the post-test Stroop task (M = 124.259, SD = 20.809) was significantly lower than the pretest (M = 129.178, SD = 21.823), demonstrating a medium effect size (t = 2.476; p = 0.021, Cohen's d = 0.45). A reduction in total time required to complete the task represents a composite improvement in psychomotor speed and cognitive flexibility (Bajaj et al., 2015).

Results for cognitive performance were further supported by EEG data. Multiple analysis of variance (MANOVA) with four mental indices as dependent variables and condition as the predictor, demonstrated significant differences across all conditions between biking and the post-test. As seen in Table 1 and Figure 1, changes in mental indices trended in directions conducive to higher cognitive performance. Specifically, focus (frontal β/α) increased significantly during the bike ride and remained higher during the post-test. Relaxation (global α) demonstrated a positive linear trend from pretest through post-test. Motivation (i.e. frontal asymmetry) and inward attention (frontal θ) demonstrated quadratic trajectories, indicating enhanced mood and less withdrawal after biking.

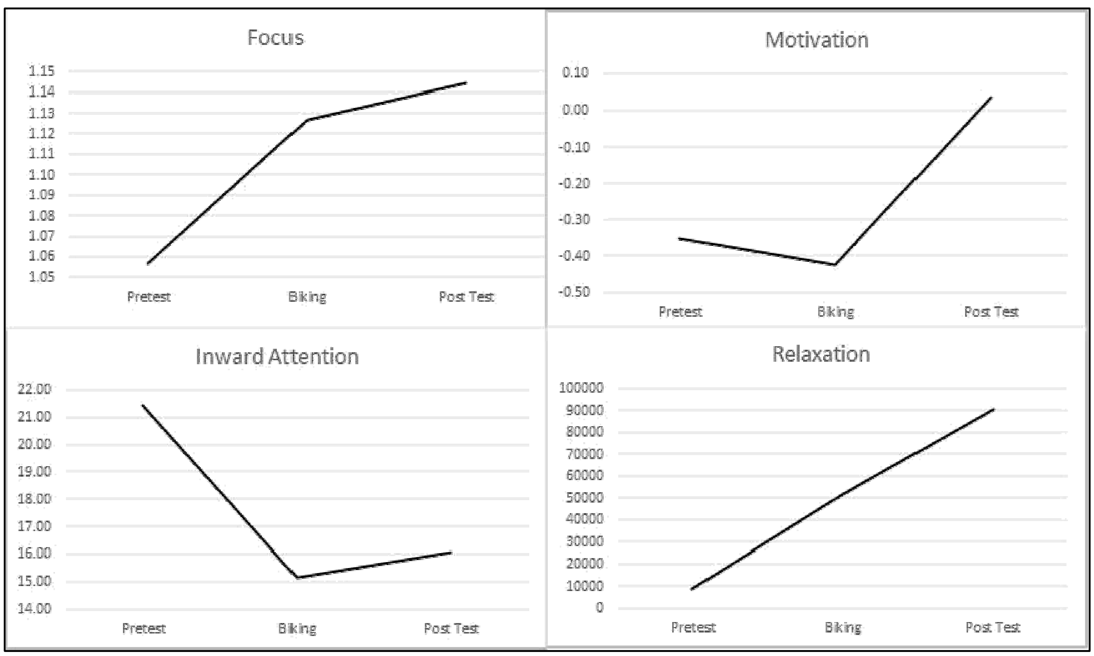

Figure 1. Trajectories of EEG indicators illustrating changes induced by a short biking experience.

Table 1

MANOVA results for EEG indicators across time points.

category		Mean	Std. Deviation	F	Sig.	Eta Squared	Cohen's *d*
Focus	Pretest	1.057	0.722				
	Biking	1.126	0.796	20.959	0.000	0.001	0.060
	Post Test	1.144	1.627				
Motivation	Pretest	-0.351	0.737				
	Biking	-0.424	0.789	3732.967	0.000	0.087	0.617
	Post Test	0.036	0.486				
Inward Attention	Pretest	21.442	28.279				
	Biking	15.155	16.967	449.469	0.000	0.011	0.211
	Post Test	16.068	16.631				
Relaxation	Pretest	8592.090	29185.115				
	Biking	51628.530	99429.390	2381.690	0.000	0.057	0.492
	Post Test	90690.824	131919.744				

Discussion

Findings indicate that a short biking intervention can improve performance on a working memory task, with an effect size (0.45) equal to that reported in previous exercise research (0.20 – 0.43; Biddle et al., 2019). An improvement in psychomotor speed and task-switching capacity after physical activity is consistent with previous research, and confirms that a short dose of moderate exercise can induce significant, albeit temporary, cognitive impacts. Exercise has been connected with broad protective outcomes, varying by intensity and duration of participation (Biddle et al., 2019; Heath et al., 2012). Our findings lend support to previous findings with data collected *in situ*, during a typical high school class period.

EEG data provide insight into the possible mechanisms behind the cognitive changes. Low focus and high inward attention during the pretest are indicative of a distracted mind, struggling to filter irrelevant stimuli in order to direct attention toward the Stroop task. Clear and significant changes in these indices occurred during the bike ride and persisted through significant cognitive loads induced by the post-test. Relaxation was also augmented during the bike portion, and continued to grow through the duration of testing. Motivation demonstrated a slight decline during biking, with a robust increase during the final post-test stage. It is unclear why valence was the only index to reflect a negative trend during the bike portion, but it could be indicative of discomfort induced by mandatory exercise or unease due to novice biking skills. Previous research has reported improvement in biomarkers for relaxation and focus after exercise (Bailey et al., 2018; Gutmann et al., 2015). These findings explicitly connect changes in cortical activity experienced during a short bike ride to improved cognitive scores immediately thereafter.

A few methodological concerns for this study include the lack of randomization, limitations of the working memory test, and the lack of comparison during a non-biking task. It is possible, for instance, that the improvement in test scores was simply indicative of learning how to perform a Stroop task. Although, post-hoc analyses revealed a decline in performance as the test dragged on and participants' focus waned. As such, a visual working memory test may prove less draining. Additionally, cognitive and neuronal changes could be identical with an intervention lacking an aerobic component. To address these concerns, another study was conducted with a repeated-measures design, to compare working memory performance and neuronal activity both during biking and while seated, watching an instructional video.

Study 2

Sample and Procedures

Twenty-one middle school students participated in this second study (12 female; *Mean* age = 11), which took place during two standard physical education classes. Two 7th grade classes (n = 10) met at the beginning of the day (8am) and one section of 6th graders (n = 11) met in the afternoon (1:30pm). A stratified random design was applied, with two classes participating in the biking condition first, and then repeating the process with a resting condition on the second day. One of the 7th grade classes participated in the resting condition first, followed by the biking activity. While a completely randomized design with identical timing would have been ideal, limitations established by school administrators precluded a time-intensive process. All students proceeded in the same manner as the previous study, performing cognitive tests on portable devices before and after each condition, while wearing EEG headsets and fitness trackers throughout.

Cognitive tests for this experiment included the Match to Sample (MtS) test, measuring short-term memory as stored by the visual sketchpad (Baddeley, 1981). This measure was utilized to assess the independent VWM system, and to minimize interference from literacy and inhibitory demands inherent in the Stroop task. In this test, participants were presented with a pattern (e.g. a 2-dimensional rubik's cube with two colors), then asked to select the pattern they just viewed from a presentation of two similar patterns. The patterns were presented for 1000ms on a 4 x 4 grid with tiles randomly colored in red or blue. The test includes 32 trials of patterns, evenly split across two possible delay conditions (1000 milliseconds and 5000 milliseconds). After completing the MtS test, students were asked to perform the Alternative Uses Test (AUT; Guilford, 1967), during which they wrote down as many uses for a predetermined word (i.e. cup), as they could conjure. This measure of divergent thinking is common in creativity assessments, implying inter-hemispherical connectivity in the cortex. Commensurate with scoring recommendations, responses were assessed for originality (i.e. no other students mentioned it), fluency (i.e. total number of ideas), flexibility (i.e. categories of uses), and elaboration (i.e. specificity and descriptiveness), and analyzed as a composite score.

Students completed both tests before and after biking, and a second time before and after a resting condition. For this study, the resting condition consisted of watching a 15-minute video describing basic mountain bike maintenance. This condition was utilized to maintain consistency of mental activity for the resting students without inducing a heavy cognitive load. The condition also mimics the delivery of curriculum the students experience most of the school day. All biking conditions were conducted on clear weather days and all video conditions were conducted indoors, using a projector and loud speaker. EEG methods and measures were identical to the first study, with the exception of one additional indicator, theta/beta ratio, for comparison with alternative procedures (e.g. biofeedback). This indicator is essentially the quotient of Inward Attention/Focus, and provides a reliable measure of mental attention ($A = \theta/\beta$ af3 + θ/β af4).

Results

Given age differences and divergent schedules, preliminary tests were conducted on baseline mental status of 6th and 7th grade students. One-way ANOVAs revealed a significant difference for Focus, at baseline, with 6th graders presenting higher beta wave amplitudes at rest before testing (F = 6.012, p = .02). While elevated beta could indicate higher attentional resources under load, this index more likely represents a "busy brain" that is, perhaps, depleted from hours of academics (Thompson et al., 2015). Accordingly, 7th graders with less busy brains scored higher on the pretest MtS test (F = 6.305, p = 0.34). Thus, age group and baseline focus levels were included as independent variables in subsequent analyses. MtS tests and AUT were analyzed with an ANCOVA using age group and bike/rest as the conditions, pretest scores and baseline focus as covariates, and post-test as the dependent variable (see Table 2). Though the mean scores were higher after biking (Cohen's d = .235), there was no significant effect for bike/rest on the MtS test nor on the AUT test. There was a significant age group * bike/rest interaction for MtS tests (F = 4.308; p = 0.045; ηp^2 = 0.126) but not for AUT outcomes (F = 0.691; p = 0.413; ηp^2 = 0.023). Given a significant group x condition interaction (Cohen's d = 0.398), post hoc analyses were conducted for each group separately. The 7th graders demonstrated a non-significant reduction in cognitive performance after biking, as compared to the video. The younger students presented the opposite trend, with significantly higher MtS outcomes after biking than after the video (Cohen's d = 0.535). Potential influencers of these results are presented in the discussion below (e.g. testing time, weather).

Table 2
ANOVA results for the influence of biking on Match to Sample and Alternative Uses Tests.

Source	Group	Mean Biking	SD Biking	Mean Video	SD Video	F	Sig.	Partial Eta Squared
MtS	Both Groups	0.685	0.208	0.672	0.239	0.557	0.460	0.014
MtS	6th grade only	0.694	0.223	0.541	0.226	6.830	0.018	0.287
MtS	7th grade only	0.677	0.219	0.790	0.190	0.752	0.396	0.036
AUT	Both Groups	10.375	5.709	11.157	8.852	0.021	0.884	0.001
AUT	6th grade only	10.000	4.898	13.333	9.205	0.368	0.552	0.021
AUT	7th grade only	10.692	6.498	9.200	8.508	0.382	0.543	0.019

EEG measures demonstrated similar patterns to the first study, with neural indicators improving after the biking condition, and negative trends or no change after the video (Table 3 & Figure 2). To illustrate divergent, between-group trajectories, data were analyzed with repeated measures ANCOVAs, using ten-second initial baseline measures as a covariate and condition as the between-groups factor. Due to noisy data and/or poor connectivity for the entirety of the two sessions, complete EEG data were only available for 17 of the 21 participants. Given the "universal" fit of the headsets, there are occasions where the reference node loses connectivity with the mastoid process, either due to the shape of the cranium or an unintentional adjustment of the bike helmet. As this is a hardware/software issue and not a lack of participation or inclusion, the loss of data can be considered missing at random (MAR). In this case, missing data were handled through pairwise deletion. As shown in Table 3 and Figure 2, the video condition had little influence on any of the EEG indexes, but the biking condition induced quadratic changes in all indicators, with all trajectories except Motivation reaching significance. Changes in the theta/beta ratio indicating focused attention equated to a strong Cohen's d effect size of 0.746. These results support previous findings with the added rigor of a resting condition, and tie mental status indicators directly to the biking activity. To be thorough, post hoc analyses were also conducted separately for the 6th and 7th grade groups for all EEG measures, with no significant interactions emerging.

Table 3
RM ANCOVA results for EEG indicators across time and conditions.

	Time point	Bike *Mean*	Bike *SD*	Rest *Mean*	Rest *SD*	*F*	Sig.	Eta Squared
Relaxation	Pretest	11668.641	21821.597	3603.527	11481.184			
	Condition*	121440.519	136866.091	3504.454	12087.59	10.819	0.002	0.265
	Post test	5897.398	17505.83	655.755	834.653			
	Pretest	1.801	2.343	1.64	1.444			
Motivation	Condition*	41.893	164.395	1.364	1.641	2.482	0.092	0.076
	Post test[a]	165.83	678.503	1.48	1.948			
	Pretest	1.367	0.521	1.309	0.539			
Focus	Condition*	0.929	0.204	1.478	0.714	5.975	0.002	0.292
	Post test	2.132	0.809	1.278	0.809			
Inward	Pretest	13.126	10.191	19.489	17.233			
Attention	Condition	17.582	9.686	18.658	28.922			
	Post test	8.508	8.188	38.85	67.808	6.228	0.006	0.300
	Pretest	6.318	0.796	6.198	1.108			
Theta/Beta	Condition[a]	6.628	0.299	6.123	0.961			
	Post test*	5.226	2.206	6.209	6.208	4.409	0.040	0.128

* *Trajectories divergent from Pretest* ($p \leq .05$); [a] *Trajectories divergent from Pretest* (p < .1).

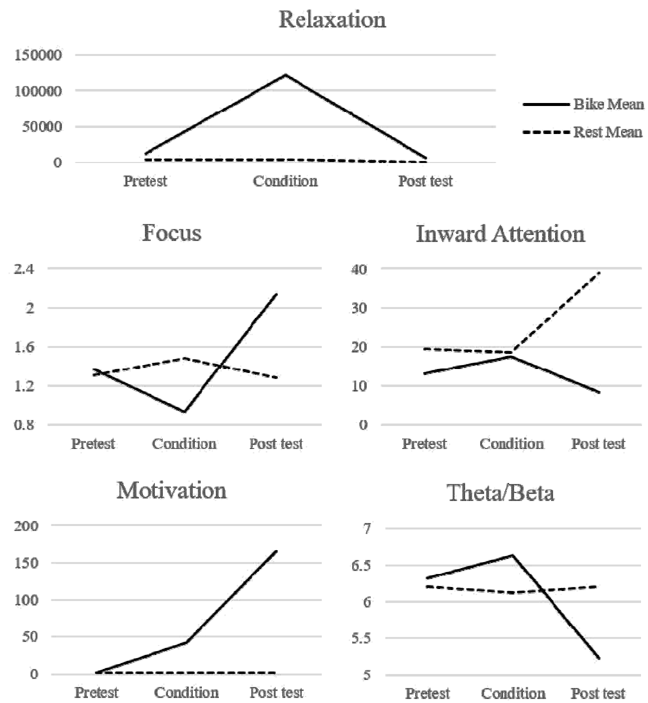

Figure 2. Trajectory of EEG indicators by time and condition.

Discussion

These results confirm the influence of a brief, medium-intensity biking event on neurological activity. Relaxation, motivation, and attention indicators all demonstrated improvement attributable to the biking condition. Only the 6th grade sample showed significant improvements in cognitive performance due to the biking intervention, and neither group demonstrated lasting, augmented creativity. Divergent results are likely attributable to limitations in study design, as the younger group participated later in the day, exhibiting greater mental distraction at baseline. A program aimed at restoring attention would be more impactful if implemented after significant mental depletion, and not first thing in the morning. Lower temperatures during the morning bike ride may have also confounded results. Previous research has shown that exposure to temperatures below 50 degrees F can impede cognition (Muller et al., 2012). Temperatures during the morning sessions (7th grade) in our study were in the low 40's, while 6th grade students enjoyed a bike ride in sunny, 65 degree F weather during the afternoon class. As such, practitioners employing physical activity to combat mental fatigue may be advised to avoid extreme temperatures and schedule activity interventions around times of peak mental depletion. Biddle et al. (2019) noted that research did not necessarily support the inclusion of physical education in schools as a method of meeting recommended physical health guidelines. However, short exercise interventions may prove helpful for attention restoration, if implemented intentionally.

Changes in EEG indicators were consistent for both studies, with improvements showing medium to strong effects. The immediate effect of a brief biking intervention on theta/beat ratio (d = .746), for example, rivals that reported by medically-approved neurofeedback treatments (d = .75) for 6-13 year-olds (Arns et al., 2013). This measure has been approved by the FDA for the diagnosis of Attention Deficit Disorders (ADD), and is commonly employed in clinical biofeedback interventions (Arns et al., 2013). While ADD was not a primary focus of this research, changes in validated symptoms are instructive for comparison. Regardless of immediate, temporal changes in cognitive performance, long-term improvements in EEG-based attention indices reflect positive mental health and aptitude in adolescents. Though promising, neuro-plasticity demands repetitive reinforcement to facilitate connections in positive neural pathways (Thompson et al., 2015). A single biking intervention may augment focus and inhibit withdrawal temporarily, but continual reinforcement is required to rewire those connections with a durability to influence long-term behavior and cognition.

Conclusions

These studies support the utilization of short, mid-intensity, physically active experiences to enhance healthy neural pathways and restore mental attention. Results from both studies provide consistent evidence to support the research questions. Neurological activity changed during and after the biking event, elevating indices for focus, motivation, and relaxation. These indices were also associated with improvements in working memory, though most effective for those exhibiting signs of mental distraction. Thus, substantial but temporary mental impacts can be gleaned through short doses of medium-intensity physical activity in public schools.

Administrators should take note that routine physical activity in schools may support academic goals and mental health. Future research will address the limitations in these study designs, including: small sample sizes, lack of randomization and control groups, and inconsistent timing of intervention testing. Despite deficiencies, the findings are consistent with previous research, and demonstrate an explicit connection between neural mechanisms and cognitive performance, as influenced by physical activity. Future research may determine the requisite dosage, frequency, and intensity to enhance mental health and performance, as well as supporting long-term physical and mental health and the prevention of disease.

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